Development of a Sodium LIDAR for Spaceborne Missions

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NASA Goddard Space Flight Center
April 21, 2015

Sodium lidar instrument

AGENDA

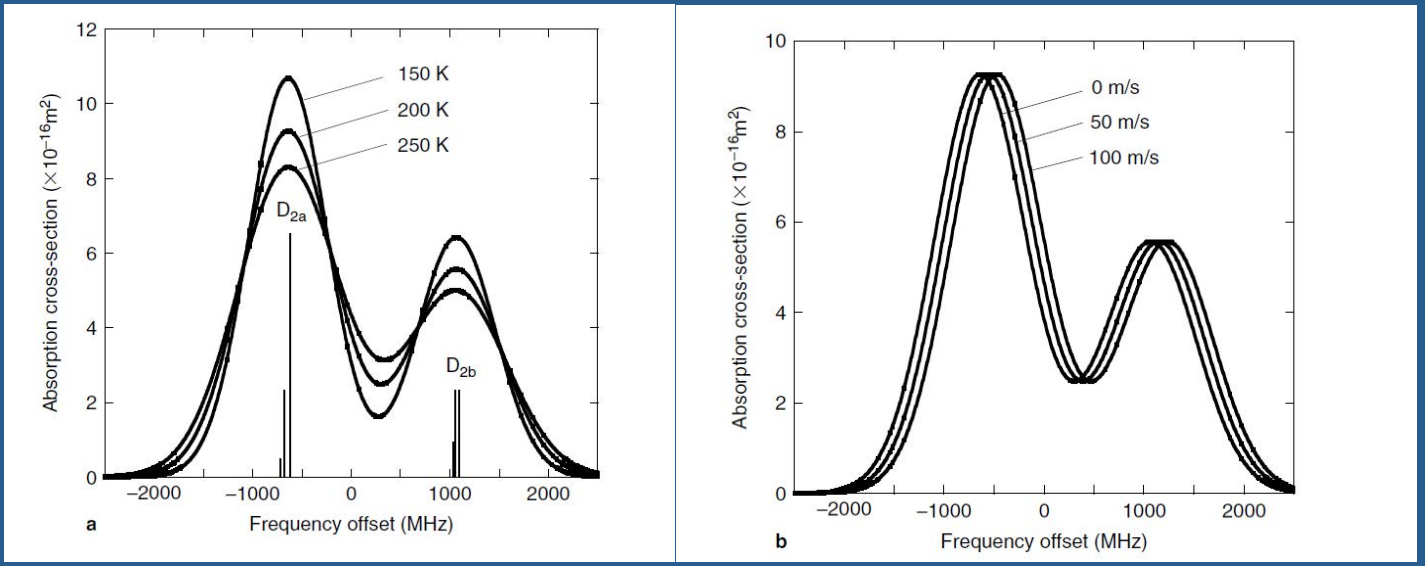
- Heliophysics in the Earth mesosphere with spectroscopy of sodium
- Key candidate technology for space-based sodium lidar:
  - Laser transmitter: Self-Raman Nd:YVO_4
  - Laser spectroscopic technique: leverage from ASCENDS
  - Laser receiver: filter
  - Laser receiver: single photon detectors

Heliophysics with sodium lidar

- **Ablation from meteors** is believed to be the chief source of **metals** such as Na, Mg, K, Fe, and Ca in the **middle atmosphere.**
- Metal (e.g. sodium) fluorescence lidar can provide temperature measurements in the Earth's atmosphere mesopause region (75 - 115 km).
- This will enable scientists to delineate and understand the middle and upper atmosphere chemistry, structure and dynamics, especially the impact of gravity waves – the parameterization of which is a fundamental issue in current atmospheric modeling for climate and meteorology.
- **In summary, this helps to delineate and separate solar vs. Earth induced heat causing change in the Earth atmospheric temperature.**

Atmospheric Sodium spectra
Temperature and wind effects

- The D2 resonance line of atomic sodium is **589.159 nm**
- The D2 resonance line of Na is a Doppler broadened doublet composed of six hyperfine lines as shown below.



- The Doppler **broadening of the lines** is a **function of temperature** and the ratio of the D2a peak to the value at the minimum between the peaks is a very sensitive function of temperature.
- The **wind speed** may be inferred from the **Doppler shift** induced to the structure of the line as shown above.

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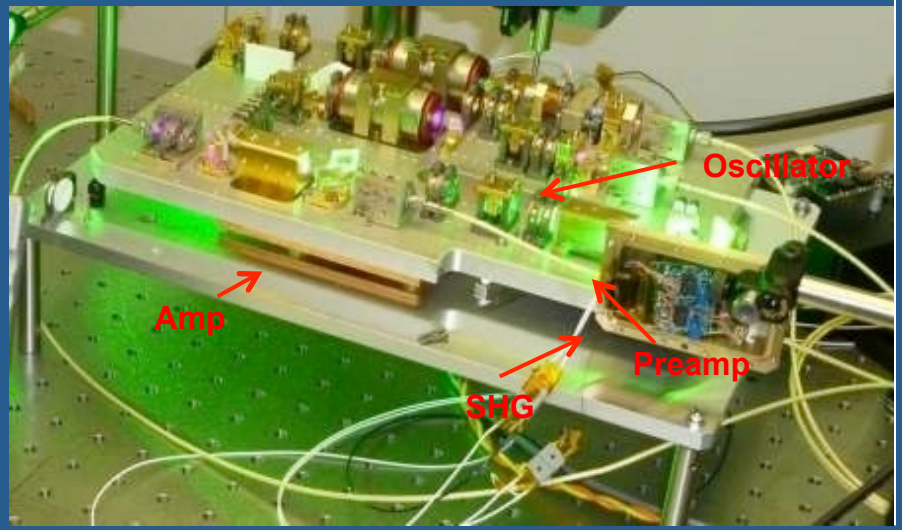
Sodium space-based lidar - leverage

ICESat2/ATLAS laser

ICESat = Ice Cloud & land Elevation Satellite
ATLAS = Advanced Topographic Laser Altimeter System **2017 launch**

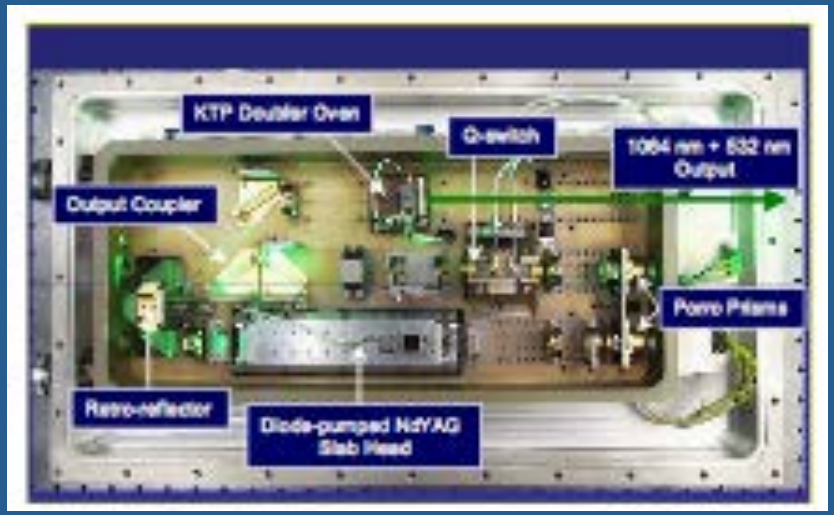
9W @ 532 nm Nd:YVO_4 laser built by Fibertek Inc.



CALIPSO/CALIOP laser

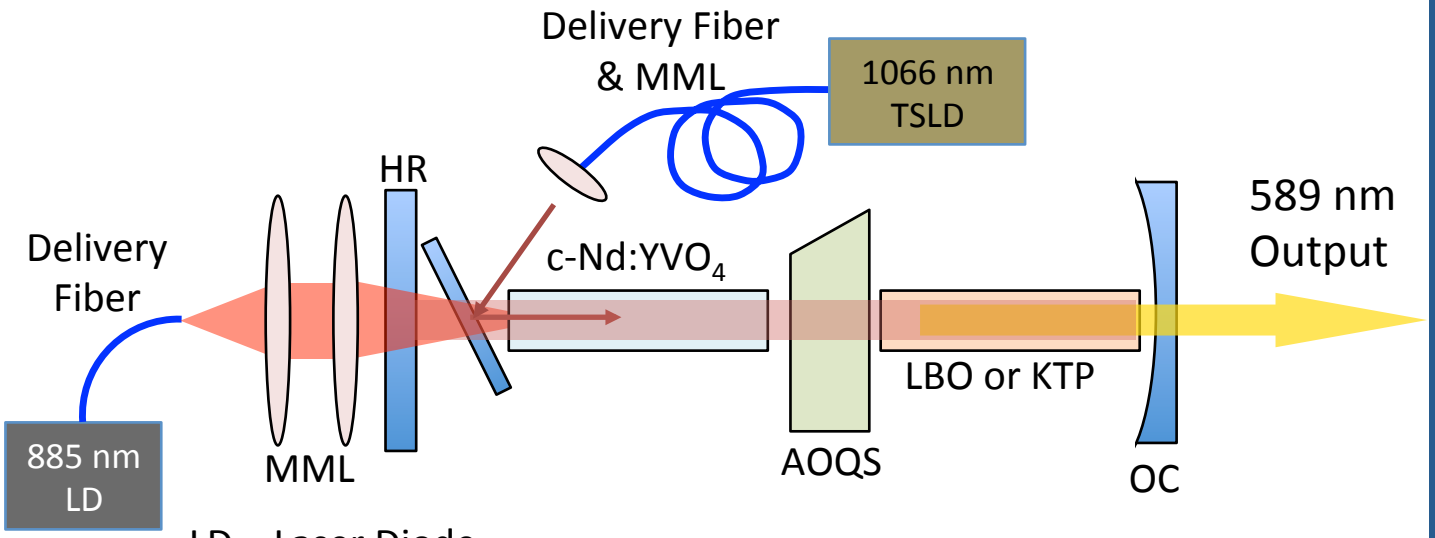
CALIPSO = Cloud Aerosol Lidar and Infrared Pathfinder Satellite Observations
CALIOP = Cloud-Aerosol LIdar with Orthogonal Polarization **2006 launch**

2.2 W @ 532 nm, 2.2W @1064 nm Nd:YAG laser built by Fibertek Inc



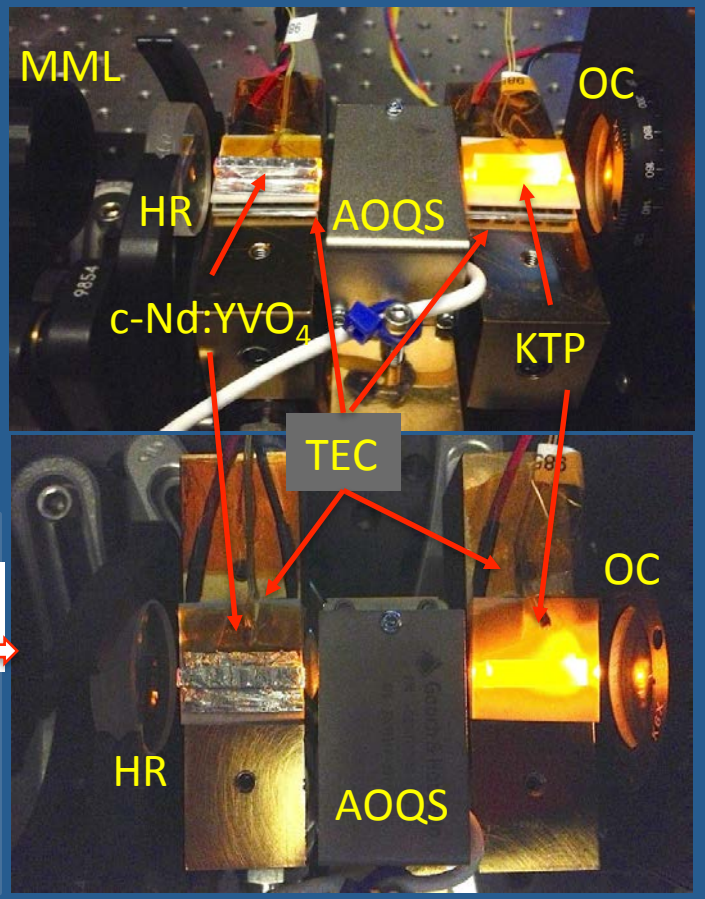
REFERENCE: F. Hovis, et al., "High efficiency laser designs for airborne and space-based lidar remote sensing systems," Proc. SPIE 8159, 815903 (2011).

Self-Raman Nd:YVO4 Laser for Sodium Spectroscopy



LD – Laser Diode
TSLD – Tunable Seed Laser Diode
MML – Mode Matching Lens
HR – High Reflective Mirror
OC – Output Coupler
AOQS – Acousto-Optic Q-Switch
c-Nd:YVO_4 – c-cut Neodymium doped yttrium orthovanadate crystal
LBO – Lithium Triborate
KTP - Potassium Titanyl Phosphate

Nd:YVO4 Self-Raman laser
NASA-GSFC breadboard



LD – Laser Diode
MML – Mode Matching Lens
HR – High Reflective Mirror
OC – Output Coupler
AOQS – Acousto-Optic Q-Switch
c-Nd:YVO_4 – c-cut Neodymium doped yttrium orthovanadate crystal
KTP – Potassium Titanyl Phosphate
TEC – Thermoelectric Cooler

From LD

0.5 W at 589 nm

Laser for Sodium Spectroscopy
Tuning vanadate

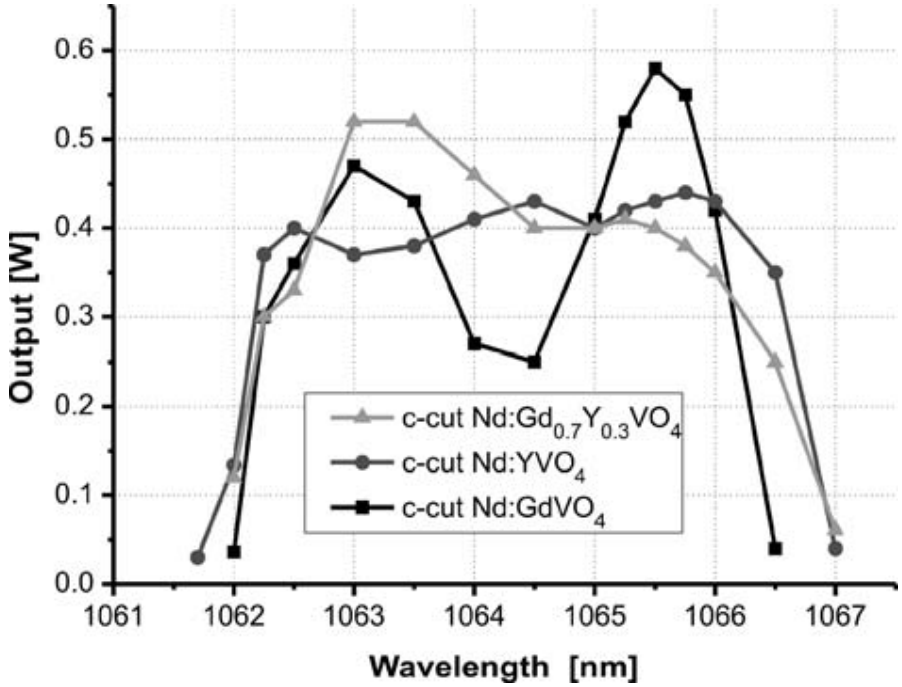
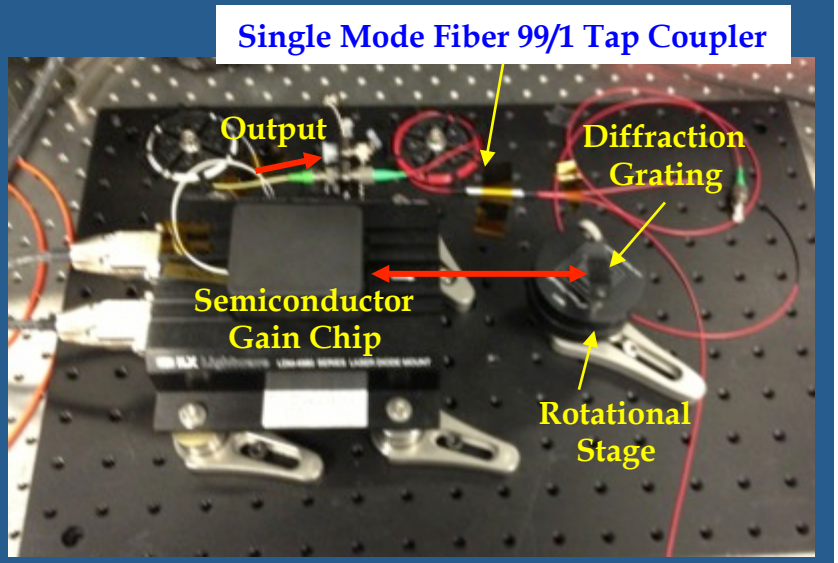


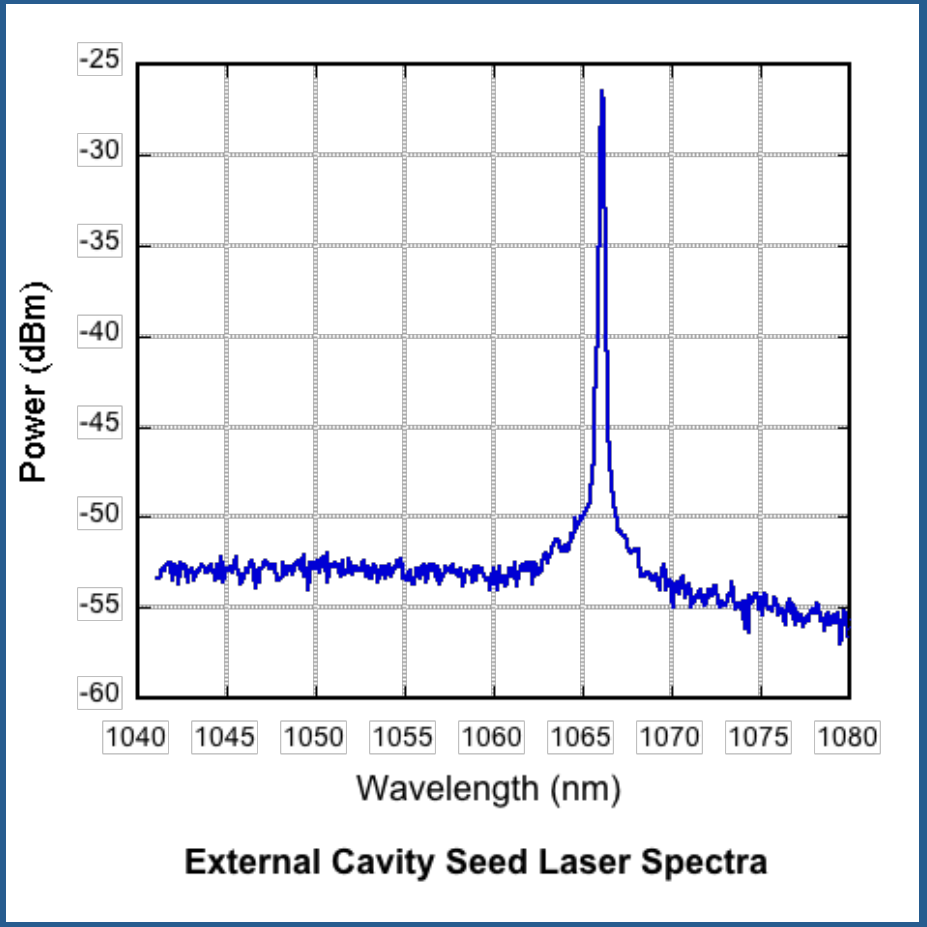
Fig. 3 The tuning curves of c-cut Nd:$Gd_{0.7}Y_{0.3}VO_4$, Nd:YVO_4 and Nd:$GdVO_4$ lasers

From: A.A. Sirotkin et al., " Mode-locked diode-pumped vanadate lasers operated with PbS quantum dots," Appl Phys B (2009) 94: 375–379

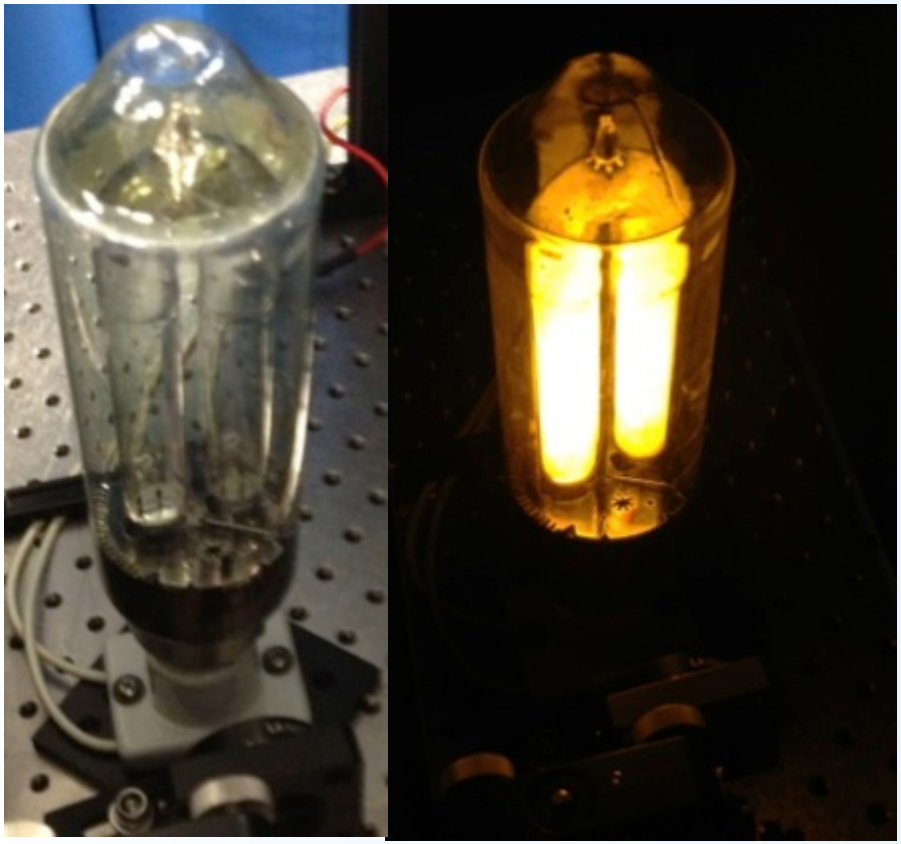
1066 nm External cavity laser (ECL) – Tunable injection seeder

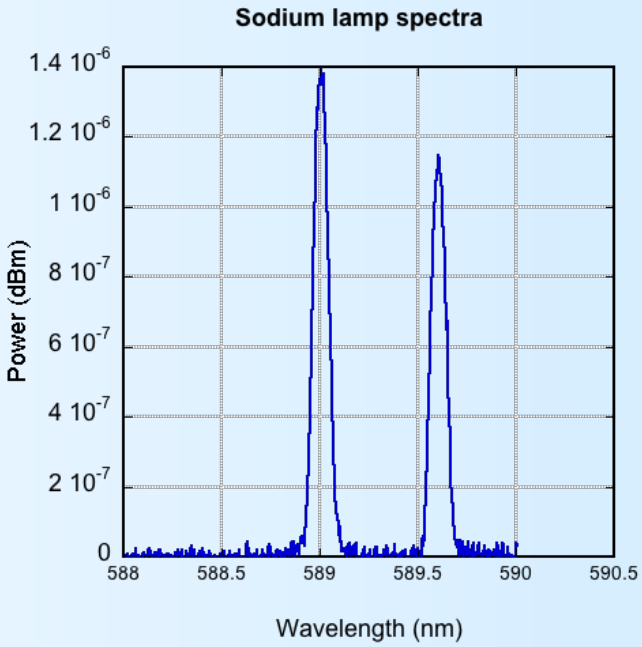


Tunable external cavity seed laser

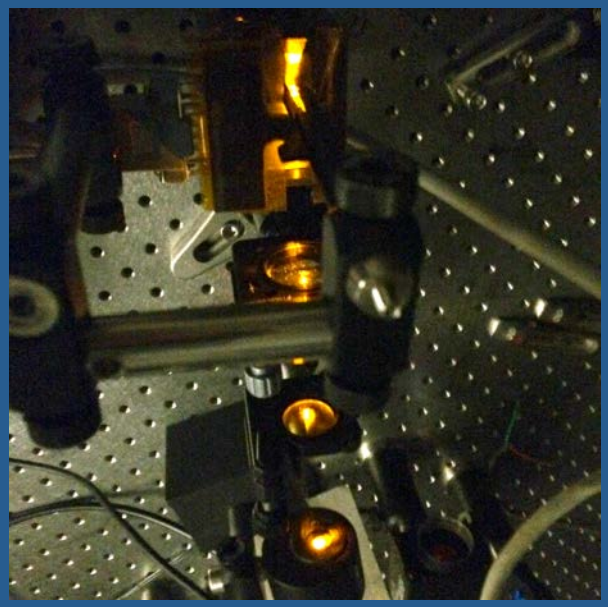


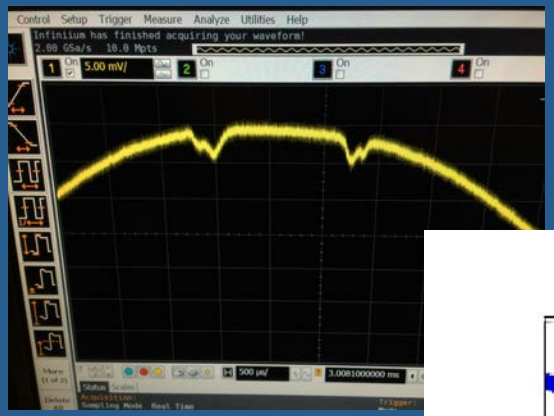
Sodium line (lamp) calibration source

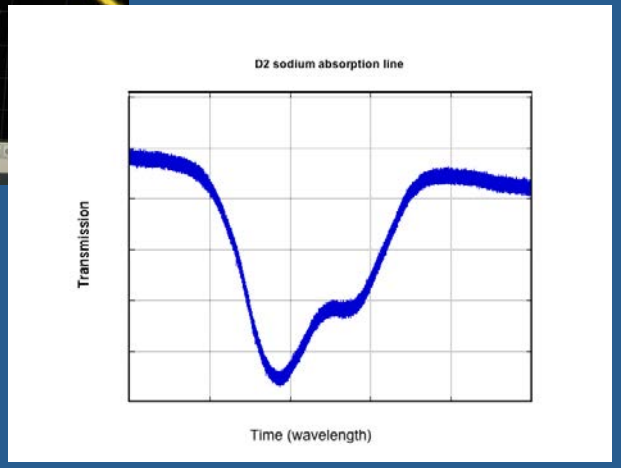




Laser spectroscopy of sodium vapor







- Performed real-time experimental spectroscopy of sodium vapor (in a closed cell heated to 110 C) using a frequency-doubled (1178 nm to 589 nm) Distributed FeedBack (DFB) tunable diode laser.
- The laser is tuned in real-time by modulating the electrical current input to the laser.
- The spectra is replicated because the current amplitude is increased and decreased by a sinusoidal input electrical waveform.

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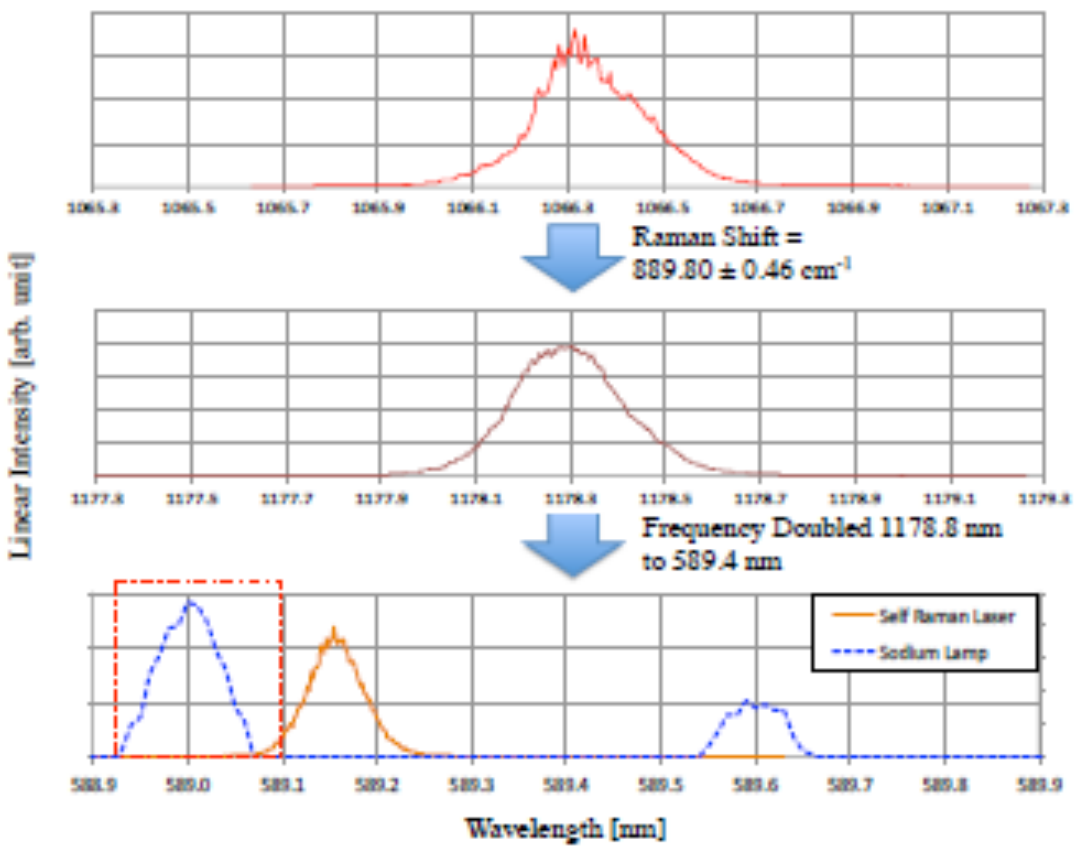
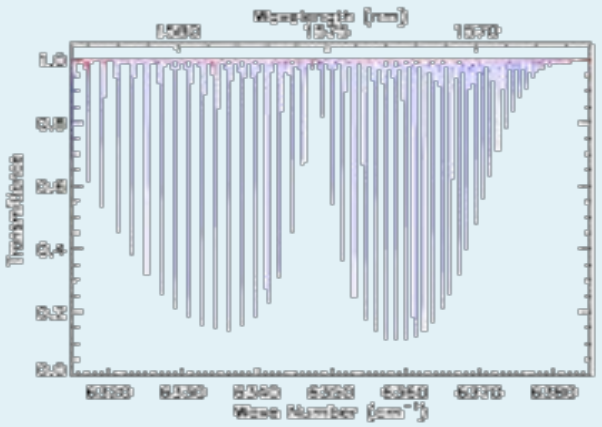
Self-Raman Nd:YVO4 laser spectra (unseeded)
NASA-GSFC breadboard

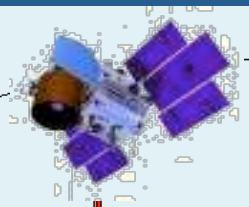


Sodium lidar instrument - leverage

Laser Spectrometer for ASCENDS Mission

Measures:
- CO2 tropospheric column
- O2 tropospheric column
- Cloud backscattering profile





~ 400 km Sun sync orbit
- CO2 at 1570 nm
- O2/pressure at 765 nm
- Altimetry & atm scattering profile from CO2 signal

Clouds and aerosol: λ=1064nm

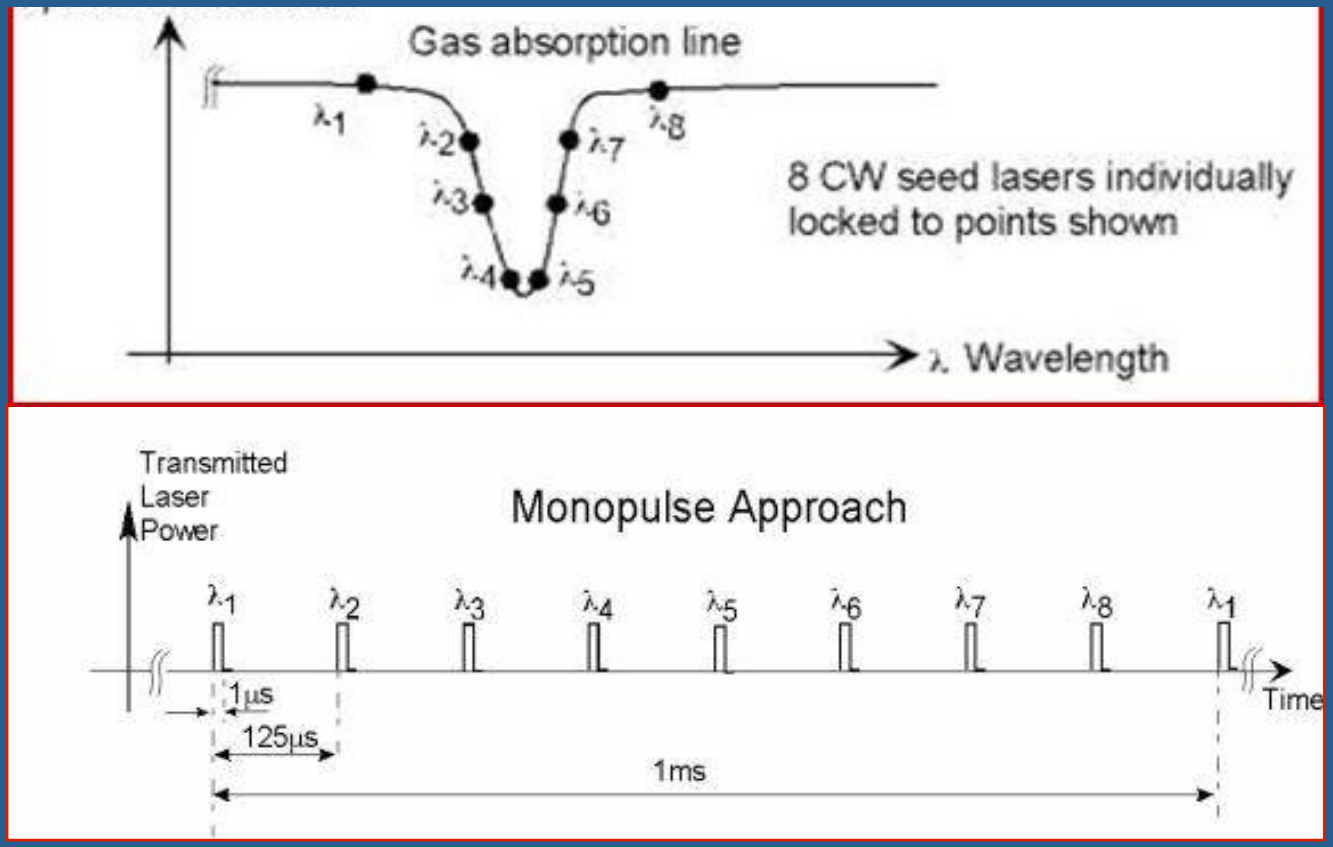
clouds

ASCENDS = Active Sensing of Carbon Emissions over Nights, Days and Seasons **2022 launch**

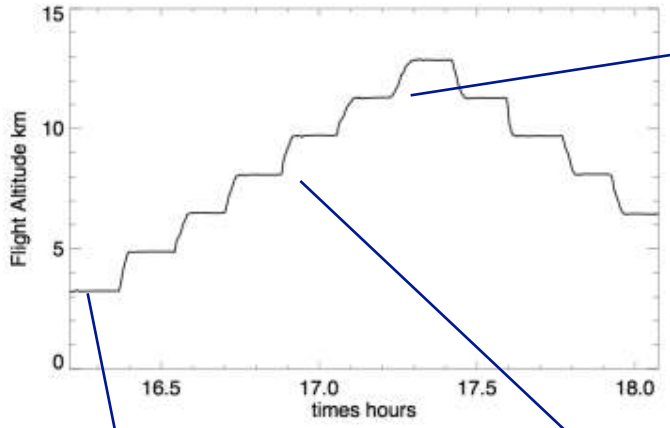
Sodium lidar leverage from ASCENDS Mission

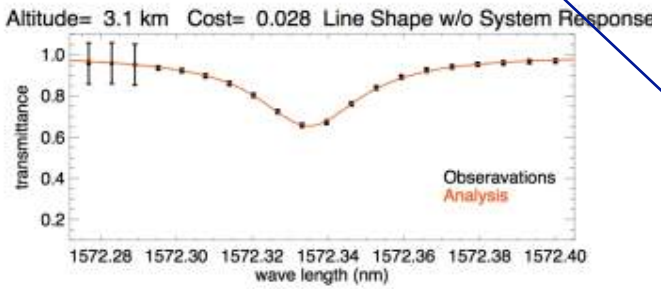
Time/wavelength multiplexing

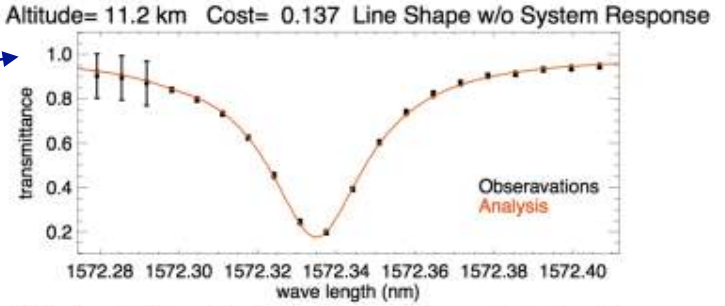
using electrically tunable DFB laser and modulator

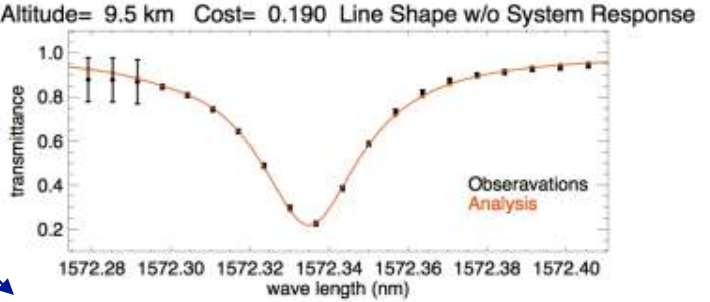


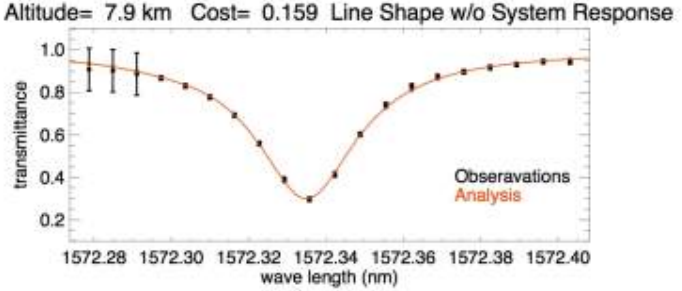
Airborne instrument retrievals of CO2 absorption line - August 4, 2009

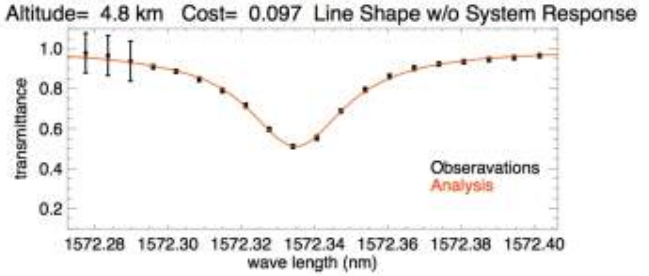


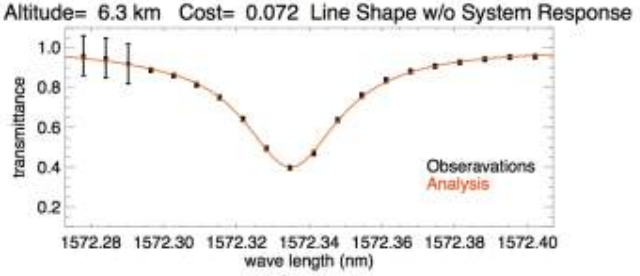












- Black dots - sampled line shape from lidar
- Typ. 60 sec ave time

- Red curves - best fit line shapes (based on HITRAN) from retrieval process

- Absorption increases with altitude
- Smooth line shapes at all altitudes !

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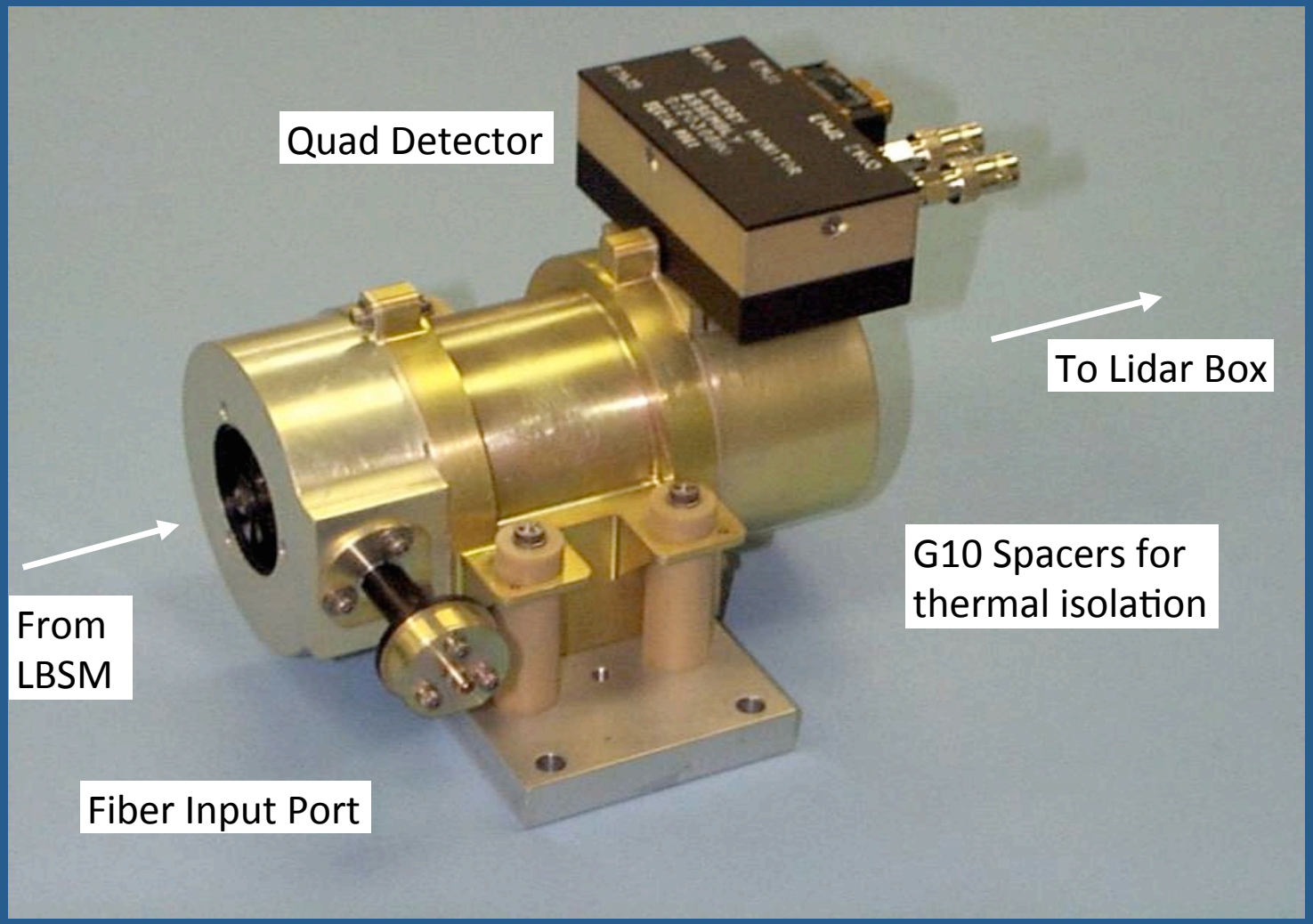
Sodium lidar leverage from ICESat/GLAS Mission

ICESat/GLAS Etalon Assembly

Also considering sodium vapor Faraday filter



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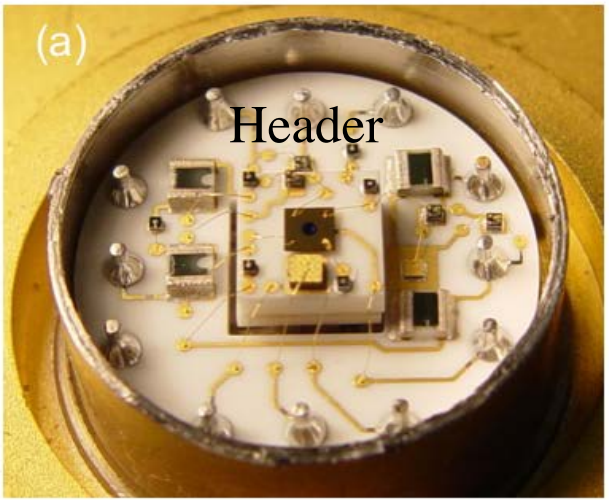
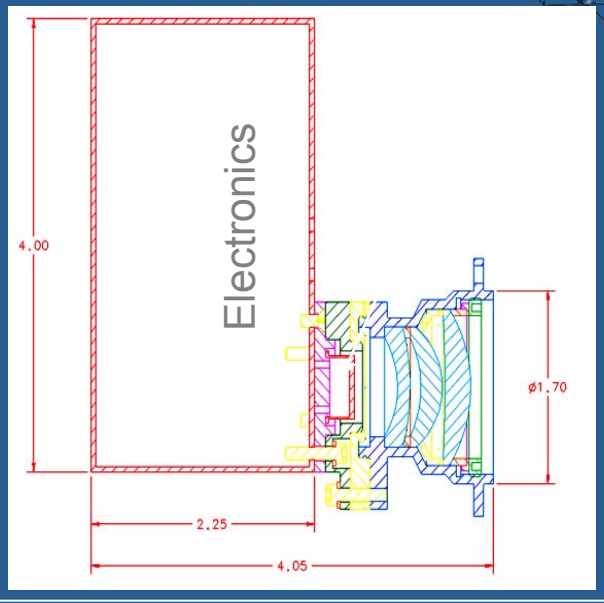
Sodium lidar leverage from ICESat/GLAS Mission

ICESat/GLAS Single Photon Counting Module (SPCM)





0.17 mm diameter active area
>65% QE at 532 nm
>13e6/s max. count rate
< 1.5% afterpulsing (500ns)
<500/s dark counts
280g (electronics with header)
2.1 W (module only)
4.8 W (with power supply)

Sodium lidar instrument
SUMMARY

- NASA-GSFC is exploring concepts for a heliophysics mission using spectroscopy of sodium in the Earth mesosphere

- We have identified key candidate technology for space-based sodium lidar:
  - Laser transmitter: Self-Raman Nd:YVO_4
  - Laser spectroscopic technique: leverage from ASCENDS
  - Laser receiver: filter
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- We have proposed (to NASA Heliophysics) development of a ground-based lidar using space-flight pre-cursor components to evolve to a space-based mission.